

**CHARACTERISTICS AND ABSORPTION COEFFICIENT OF CO₂ LASER
IN NATURAL GAS MIXTURES**

By

NORHAFIDZAH BINTI MOHD SAAD

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia
in Fulfilment of the Requirement for the Degree of Master of Science**

April 2006

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DEDICATION

To my beloved husband and son.

**Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
fulfilment of the requirement for the degree of Master of Science**

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NORHAFIDZAH BINTI MOHD SAAD

April 2006

Chairman: Associate Professor Ir Norman Mariun, PhD

Faculty: Engineering

This work was arranged to develop scientific and engineering database on the study of cw / repetitively pulsed CO₂ laser in terms of its characteristics and absorption coefficient in natural gas mixtures. The laser system is operated both in continuous wave mode as well as in pulse mode at 10.6µm wavelength range of infrared electromagnetic spectrum.

The study on CO₂ laser system consists of two parts. In the first part, the measurements on the characteristics of cw / repetitively pulsed CO₂ laser system are done at 10.6 µm wavelength. The output parameters of CO₂ laser are carried out in detail to determine the laser characteristics for getting maximum output energy and power subject to various variable such as pulse repetition rate, discharge current, duty cycle and pulse duration. Different aspects of CO₂ laser are studied to determine the laser characteristics between various design parameters and the effect of varying one parameter on others. The frequency and current

limits regarding maximum and minimum output energy and power are presented. The maximum pulse energy is achieved at 32mJ when the laser operated at 10mA discharge current with 50 Hz pulse repetition rate. A maximum power of about 11 watts is measured at a current of 10mA. The output energy and power is found to decrease with further increase in pulse repetition rate and discharge current. This is due to the saturation of the gas molecules inside the laser tube.

In the second part of the project, the experimental work on the absorption coefficient of CO₂ laser in compressed natural gas mixtures are measured at variable laser energy and pressures operated at 295K temperature. The measurements are done using optical transmission loss technique with 19% transmission loss due to the absorption by the optical system. The absorption data showed a strong dependence on both laser energy and pressure. It was found that natural gas mixtures absorb laser light the most, followed by pure natural gas and the lowest laser absorption coefficient is air. The results are found to follow the exponential law of absorption that is called as Beer-Lambert Law.

The purpose of this study is to explore the application of CO₂ laser especially in the area of combustion of natural gas. For the first step, the characteristics in terms of laser energy and power and its absorption in natural gas need to be studied.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**CIRI-CIRI DAN PEMALAR PENYERAPAN LASER CO₂ DI DALAM
CAMPURAN GAS ASLI**

Oleh

NORHAFIDZAH BINTI MOHD SAAD

April 2006

Pengerusi: Profesor Madya Ir Norman Mariun, PhD

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Kajian ini bertujuan untuk membangunkan data-data saintifik dan kejuruteraan terhadap ciri-ciri sistem laser CO₂ serta pemalar penyerapan laser tersebut terhadap campuran gas asli. Sistem laser CO₂ yang beroperasi secara gelombang terus atau denyut berkala telah dilakukan pada panjang gelombang 10.6 μm pada spektrum electromagnet infra-merah.

Kajian ini terbahagi kepada dua bahagian. Pada bahagian pertama, kajian secara eksperimen ke atas ciri-ciri sistem laser CO₂ telah dilakukan. Parameter-parameter sistem laser tersebut dibincangkan secara mendalam bagi menentukan ciri-ciri laser bagi mendapatkan keluaran tenaga dan kuasa maksima yang bergantung kepada pelbagai pembolehubah seperti kadar pengulangan denyut, arus discas, tempoh denyut dan kitar tugas. Tenaga maksima diperolehi apabila laser

beroperasi pada arus 10mA dengan frekuensi 50Hz iaitu sebanyak 32mJ. Kuasa maksima pula diperolehi sebanyak 11 watt iaitu pada arus 10mA. Selepas melepasi nilai tenaga dan kuasa maksima tersebut, keluaran tenaga dan kuasa didapati berkurang dengan pertambahan frekuensi dan arus. Ini disebabkan molekul gas di dalam tiub laser menjadi tepu.

Pada bahagian kedua, pemalar penyerapan laser CO₂ di dalam campuran gas asli termampat diukur pada suhu 295K terhadap pembolehubah tenaga laser dan tekanan gas. Pengukuran dilakukan menggunakan teknik kehilangan penghantaran optik dengan andaian 19% kehilangan disebabkan penyerapan oleh sistem optik. Didapati campuran gas asli menyerap tenaga laser paling banyak, diikuti oleh gas asli dan udara. Keputusan yang diperolehi menepati peraturan penyerapan yang dikenali sebagai Hukum Beer-Lambert.

Tujuan kajian ini adalah untuk mengkaji penggunaan laser CO₂ terutama di dalam penyelidikan berkaitan pembakaran gas asli. Sebagai langkah pertama, ciri-ciri sistem laser CO₂ dan pemalar penyerapan terhadap gas asli perlu dikaji.

ACKNOWLEDGEMENTS

First of all, with the humble gratitude, I would like to express my thanks and deepest praise to The Most Gracious and Most Merciful ALLAH Who has given me all strength, faith, confidence and patience to complete this project.

It would be my pleasure to express my most sincere thanks to my supervisor Assoc. Prof. Ir Dr. Norman Mariun and members of my supervisor committee Assoc. Prof. Dr. Nasrullah Khan and Pn. Nurul Amziah for their advice, understanding, support, criticism, guidance and co-operation in completing this thesis.

I would like to express my appreciation to Kolej Universiti Kejuruteraan & Teknikal Malaysia (KUKTEM) for their generous financial support. Without them, this thesis would be a great burdon.

Finally, I would like to thank Universiti Putra Malaysia, my family and all my friends especially my husband, Muhammad Fadhil Abas for their support. I pray to Allah that He rewards each a bountiful reward.

I certify that an Examination Committee has met on 12 April 2006 to conduct the final examination of Norhafidzah binti Mohd Saad on her Master of Science thesis entitled “Characteristics and Absorption Coefficient of CO₂ Laser in Natural Gas Mixtures” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follow:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledge. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NORHAFIDZAH BINTI MOHD SAAD

Date:

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LIST OF ABBREVIATIONS

<i>B</i>	rotational constant
<i>c</i>	velocity of light
CNG	compressed natural gas
CH₄	methane
cw	continuous wave
<i>d</i>	beam diameter
DC	duty cycle
DPDT	double poles double throw
<i>E</i>	laser energy
<i>E_{abs}</i>	absorbed laser energy
<i>E_i</i>	excitation energy
<i>E_m</i>	measured laser energy
<i>E_r</i>	rotational energy
<i>E_{tr}</i>	transmitted laser energy
<i>E_{trans}</i>	transition energy
<i>E_v</i>	vibrational energy
<i>E_o</i>	initial laser energy
FIR	far-infrared
<i>F_{ph}</i>	photon flux
<i>F_E</i>	electric field
	<i>f</i> focal length
<i>g_i</i>	Gaunt factor

HeNe	Helium Neon
<i>h</i>	Planck's constant
IR	infrared
<i>I</i>	focal intensity
<i>I_{thr}</i>	threshold laser intensity
<i>k</i>	Boltzmann's constant
<i>K_v</i>	absorption coefficient
LNG	liquefied natural gas
<i>l</i>	focal point length
	MIE minimum ignition energy
<i>n_e</i>	number of electron density
<i>n_{oi}</i>	population density of the <i>i</i>th ionic species
<i>P</i>	pressure
<i>P_{avg}</i>	average laser power
<i>P_{max}</i>	maximum laser power
PRR	pulse repetition rate
PRT	pulse repetition time
<i>r</i>	focal point radius
<i>S</i>	line strength
<i>t</i>	time
<i>T</i>	temperature
<i>v</i>	shock velocity
<i>Z</i>	partition function
ZnSe	zinc selenide

$\Delta t_{1/2}$	Pulse duration
Φ	equivalent ratio
θ	beam divergence
λ	laser wavelength
α	loss coefficient
α_0	small signal gain
τ	laser pulse duration
τ_{FWHM}	full width at half maximum (FWHM) pulse duration
τ_0	time at which $E(\tau_0) = E_{max}/e$, ($e = 2.7183$) calculated in equation (2.4.2)